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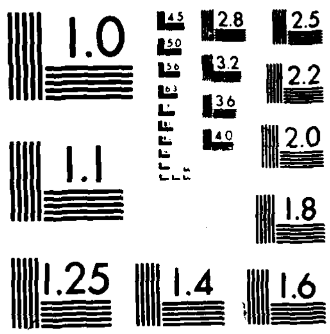

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Preliminary investigation of applying nonlinear optical effects in conjunction with the optogalvanic effect to achieve laser controlled opening switch was proposed in the low cost grant. It should be mentioned at the onset that this work was limited by the budget and that its purpose was mainly to define the problems and establish feasibilities. A crucial step is a match of mutual virtual level. Within the budget limitation, a few inportant steps were made: a) Detailed study of the plasma processes taking a major role in the opto-galvanic effect such as Penning ionization and direct electron impact ionization and their relative importance; b) the use of dye lasers according to the Raman scheme; c) Penning ionization in Hg/Ne and Sr/Ne(3) has been studied within the grant. A recent investigation the role of direct electron multistep ionization. The consequences are that although Penning ionization is an important process in the discharge it does not control it at high currents but rather the electron multistep ionization is the dominating process in sustaining the discharge. In investigating the nonlinear effect little progress was made other than formalizing and defining the problems.

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Preliminary investigation of applying nonlinear optical effects in conjunction with the optogalvanic effect to achieve laser controlled opening switch was proposed in this low-cost grant. The results of such a study are presented here. It should be mentioned at the onset that this work was limited by the budget and that its purpose was mainly to define the problems and establish feasibilities.

The idea is to utilize off-resonant laser interaction with atomic levels in order to transfer the population from the metastable state of various rare gas and mercury atoms in a discharge to their ground state. This should result in extinguishing the discharge. Since, the principal level for sustaining the discharge is the metastable state, and in effect forms a bottleneck towards ionization, the control of its population is essentially a control of the discharge. The Raman-like two-photon optogalvanic effect depicted in Fig. 1 is one such a control. The importance of the use of nonlinear optical effects is in that the control of the population of the metastable level can be effected during the periods of the laser pulses and while they produce a mutual virtual level, which can define the timing by the overlap of the two laser pulses. This idea is accentuated by our earlier finding that the radiating level has inverted population with an upper related state.[1,2] Following this nonlinear effect the radiating level will quickly relax to the ground state. Thus two lasers tuned in such a way as to match the transitions from the metastable state via a mutual virtual level will coherently drive a transfer of the metastable state to the radiating state and to the ground state. A crucial step is a match of the mutual virtual level. Such a match should be achieved both in the frequency domain and in the time domain. This requirement proves to be the main problem of the concept of the proposal. There is a need to use high power, high purity, narrow bandwidth short pulse dye lasers in good synchronization between them. Volumetric application of such two lasers in a discharge can extinguish the discharge and result in fast opening switch.

Within the budget limitation, we have made a few important steps: a) Detailed study of the plasma processes taking a major role in the opto-galvanic effect such as Penning ionization and direct electron impact ionization and their relative importance; and b) the use of two dye lasers according to the Raman scheme depicted in Fig. 1.

a) Penning ionization in Hg/Ne and Sr/Ne [3] has been studied within this grant. In a recent investigation we have addressed ourselves to the role of direct electron multistep ionization. This is discussed in detail in Appendix A which is a preprint of a paper to be submitted to the Journal of Applied Physics. The consequences are that although Penning ionization is an important process in the discharge it does not control it at high currents but rather the electron multistep ionization is the dominating process in sustaining the discharge. This is particularly apparent in switching-candidate atoms, such as mercury. Fast and volumetric manipulation of its metastable population is extremely effective in controlling the discharge.

b) In investigating the nonlinear effect we have made little progress other than formalizing and defining the problems. It is necessary to use well defined narrow band width lasers in order to mutually match a well virtual level. In essence, we wish to utilize a $1p_2 \rightarrow 1s_2$ transition similar to the one which we found to have an inverted population in neon hollow cathode discharges. This transition in combination with the $1s_5 \rightarrow 1p_2$ transition is capable of transferring population from the metastable state to the radiating state which then relax quickly to the ground state.

The idea of using nonlinear effect is that the transfer of population is realized via a virtual level close to the intermediate state and without actually changing its population. Moreover, this process should take place only during the laser pulse. Thus one must have an accurate match between the lasers and two transitions between a one virtual level close to the $1p_2$ state and the other two states.

Our experimental results obtained with broad band lasers have indicated that there is a joint optogalvanic response, namely, additive uncorrelated effects rather than a phased nonlinear one. I believe that the linewidth of our present dye lasers and their spectral purity are not good enough to obtain a match with single virtual level. In particular these lasers actually have interacted with the $1p_2$ level population that is, the process that took place is a stepwise rather than a coherent one of driving the transitions. Accurate tuning and narrow linewidth lasers are necessary for the nonlinear effects to be realized.

In summary, the main objective of this minigrant of preliminary studying the idea is achieved. We have formulated and accentuated the necessary steps which have to be taken. A well designed mercury long hollow cathode tube for volumetric interaction is needed. Also two narrow band dye lasers with $\Delta\nu \lesssim 0.01\ cm^{-1}$ and well designed synchronization among them are needed for the investigation and realization of a nonlinear optically controlled opening switch.

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Study of the direct electron impact ionization process in Ne/Hg HCD tube by the pulsed optogalvanic technique

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ABSTRACT

Direct electron impact ionization (D E I I) and the Penning ionization processes of the cathode metal vapor atoms are responsible for the discharge in hollow cathode discharge (HCD) tubes. At low current, the high density of the innert gas (usually neon), controls the discharge through Penning ionization process, while the sputtering process supplies the major part of the atoms metal vapor density . The D E I I process has a high rate only when the metal vapor density is high. In contrast, a Hg/Ne HCD tube has an exceptional behavior. Here a high density of mercury is obtained at currents above 1mA and a high D E I I rate exsists. This experimental results is detected through the pulsed optogalvanic technique. Optogalvanic signals are displayed for currents of 1.0mA and 1.3mA and they exhibit a different behavior. The physical interpretation of these observations is discussed in this paper.

INTRODUCTION

In various hollow cathode discharge tubes such as Ca/Ne, Cu/Ne etc ,the atomic vapor is produced by the sputtering process usually in low densities on the order of $10^{13}cm^{-3}$. As a result, the direct electron impact ionization of the metal vapor atoms has a very low rate and its contribution to ionization and the production of free electrons is minor to the other processes such as the Penning process. However, a Hg/Ne HCD tube provides a case in which a high density of vapor atoms is produced by thermal evaporation of the cathode at quite low currents. At high currents this density can exceed that of neon which is on the order of $10^{17}cm^{-3}$. Subsequently direct electron impact ionization rate of the metal vapor atoms becomes quite high and dominates the discharge through increasing the total ionization rate above the ionization rate created by the Penning process. This enhancement is detected through the pulsed resonant optogalvanic technique.

THE EXPERIMENTAL SETUP

The experimental setup is displayed schematically in Fig (1) It includes a nitrogen laser with power average about 30 KW and pulse width of 5nS. It pumps a nonflowing tunable Hansch type dye laser.

The dye laser has pulse energy of few microjoules, pulse width of about 3 nSec and a linewidth of 0.1 cm^{-1}. The setup consists also of an old Hg/Ne hollow cathode discharge tube (Pye unicam type) filled with about 5 torr of neon driven by a very stable D.C. power supply to allow measurements of weak optogalvanic voltage signals (O.G.S) of only few millivolts. To avoid R.F. interfering the discharge tube, its electrical circuit and the power supply are inserted inside a Faraday cage The O.G.S were coupled via a D.C blocking capacitor to an signal averager (Biomation 805) and displayed on an oscilloscope or on a chart recorder

The dye laser emission wavelength is monitorised by a Spex 1401 double monochromator.

THE THEORETICAL CONSIDERATIONS;

The discharge inside a hollow cathode discharge tube is dominated by the following ionization processes:

A) The Penning ionization process dominates the discharge at low currents when the metal vapor density is low.

B) The Direct Electron Impact Ionization process (D.E.I.I) has a high rate at high currents when the metal vapor density is high.

At low currents the Penning ionization process dominates the discharge. It involves an interaction in which an energy transfer occurs when an excited metastable atom of neon ionizes a ground state atom of mercury according to the reaction;

$$Ne^*(^3p_2,^3p_0) + Hg(^1s_0) \Rightarrow Ne(^1s_0) + [Hg^+(^2D,^2p)]^* + e^- \quad (1).$$

This is a quasi-resonant process. The levels of the neon and the mercury which involve's this kind of interaction are displayed in Fig(2). The rate of the Penning ionization is proportional to the Fermi golden rule-

$$W(r) = 2\pi \, |\langle Ne, Hg^+, e^- | V(r) | Ne^*, Hg \rangle|^2 \rho_f(\varepsilon)/h \quad (2).$$

$V(r)$ is the interaction potential, r is the internuclear distance and $\rho_f(\varepsilon)$ represents the final electrons density of states.

The whole process exhibits a quasi-resonant behavior similar to the case of the calcium discussed in references (2) and (3).

The Penning ionization's rate obey

$$dn_i(t)/dt = \gamma_p \, n(Ne^*) \, n(Hg) \quad (3a).$$

where $n_i(t)$ is the density number of Penning ionizations, the Penning ionization rate term $\gamma_p = \langle \sigma_p v_p \rangle$. According to Wren and Setser[1] the Penning ionization cross-section $\sigma_p = 7*10^{-15} cm^2$

and according to our estimations $v_p \cong 10^4$ cm/sec, $n(Ne^*) = 10^{11}$ cm^{-3}, and $n(Hg) = 10^{16}$ cm^{-3}.

The D.E.I.I process involves ionization of the metal vapor atoms by electrons. The rate for this process is propotional to the atomic density and is larger whenever the atoms are in excited levels nearer to their ionization levels. The rate of this ionization process is

$$d[n_{(i)}(t)]/\,dt = K_e\, n_e\, n \qquad (3b).$$

Where $n_{(i)}(t)$ is the density number of D E I I ionizations, the D E I I ionization rate term $K_e = \langle\sigma_e\, v_e\rangle$. For mercury atoms $\sigma_e \cong 9*10^{-15}$ cm^2 (Ref (7)), $n_e = 10^{10}$, $v_e = 6*10^7$ cm/sec and the D E I I rate $K_e = 5*10^{-8}$ cm^3/sec. Therefore $d[n_{(i)}(t)]/\,dt = 5*10^{20}$ cm^{-3}s^{-1}. The D E I I rate is related with the electrons energy distribution $n_e(\varepsilon)$ which is assumed to be Maxwellian like and is given by:

$$n_e(\varepsilon)\, d\varepsilon = [(2N/\pi^{1/2})]((\varepsilon/kT_e)^{1/2})\exp\{-\,\varepsilon/kTe\}\, d(\varepsilon/kT_e) \qquad (4).$$

N is the total electron density, and T_e is the avarage electrons temperature. For our case we assume a temperature $T_e \cong 8*10^3$ K°.

We modify the resonant pulsed optogalvanic phenomenological model by taking into consideration the case in which the high density of the evaporated atoms of mercury increases the rate of the direct electron impact ionization process up to the stage of dominating the discharge.

The Optogalvanic voltage signal (O.G.S) is given by Erez [5].

$$\Delta V(t) = -\,\beta\, \Sigma_j\, a_j\, \Delta n_j\,(t)\,. \qquad (5).$$

β is a sensitivity factor which depends on the multiplicity factor K and given by $\beta = -\partial K/\partial V$ and a_j are the change of the mutiplication

factor as a result of a change of the temporal populations in the excited states $\Delta n_i(t)$. The rate equations of the populations $\Delta n_i(t)$ in the relevant four excited states theory [2-4] are given by:

$$d(\Delta n_i)/dt = -\Delta n_i/T_i + \Sigma_{i \neq j} [\, \gamma_{ji} \;\; \Delta n_j - \gamma_{ji} \;\; \Delta n_i \,] \qquad (6).$$

where γ_{ji} are the relevant elements of the transition matrix and the excited states population density n_i that takes part in the optogalvanic effect are sketched in Fig(3) for a four level model. The population density of these levels at steady state are designated by n^o_i ;the deviation from the steady state is Δn_i and the densities n_i given by $n_i = n^o_i + \Delta n_i$. We assume that the deviation Δn_i of the level i relaxes to n^o_i with a relaxation time T_i.

These relaxation times according to this model are indicative of the coupling strength and the response of these levels to changes in the plasma ,acting as a whole. T_4 is dominated by the heavy particle ionic diffusion time and would be the longest relaxation term. now we are going to generalize this model by introducing a term $\mathbf{K_e n_e \Delta n_3}$ which is the effective direct electron impact ionization rate term. According to (6) the rate equations for the four relevants levels are :

$$d(\Delta n_1)/dt = -[1/T_1 + \gamma_P \; n_3] \; \Delta n_1 \qquad (7).$$

$$d(\Delta n_2)/dt = -[1/T_2] \; \Delta n_2 \qquad (8).$$

$$d(\Delta n_3)/dt = -\gamma_P \; n_3 \; \Delta n_1 - [1/T_3 + K_e \, n_e] \; \Delta n_3 \qquad (9).$$

$$d(\Delta n_4)/dt = \gamma_P \; n_3 \; \Delta n_1 + K_e \, n_e \; \Delta n_3 - [1/T_4]\Delta n_4 \qquad (10).$$

The initial values obey :

$$-\Delta n_1(0) = \Delta n_0 = \Delta n_2(0) = Q_{12}(n_1 - n_2) > 0 \qquad (11).$$

$\Delta n_3(0) = \Delta n_4(0) = 0.$

The term Q_{12} describes the absorption of a short pulse laser illumination resonance with the transition between the levels 1 and 2 and is given by

$$Q_{12} = \int \sigma_{12} I(t)dt \quad . \qquad (12).$$

Where σ_{12} is the absorption cross section and $I(t)$ is the laser illumination intensity. The solution of the rate equations:

$$\Delta n_1(t) = -\Delta n_0\, e^{-t/T_1*} < 0 \; . \qquad (13).$$

Where $1/T_1^* = 1/T_1 + \delta_p n_3$.

T_1^* -is an effective plasma relaxation time for the neon's metastable level which includes the *Penning process* assuming n_3 as a slowly varying quantity The solution of the other rate equations are:

$$\Delta n_2(t) = \Delta n_0\, e^{-t/T_2} > 0. \qquad (14).$$

$$\Delta n_3(t) = -\{\delta_p n_3 \Delta n_0 / a_2\} [\, e^{-t/T_3*} - e^{-t/T_1*}] \geq 0. \qquad (15).$$

The term $1/T_3^* = 1/T_3 + K_e n_e$

$$\Delta n_4(t) = \{\delta_p n_3 \Delta n_0/\alpha_2\}\{[K_e n_e (e^{-t/T_1*})/\alpha_1 - (e^{-t/T_3*})/\alpha_3)$$
$$- \alpha_2 e^{-t/T_1*}/\alpha_1] - [(K_e n_e - \alpha_2)/\alpha_1 - K_e n_e/\alpha_3]$$
$$*e^{-t/T_4}\} \qquad (16).$$

The α_i terms are define as :

$\alpha_1 = [\, 1/T_4 - 1/T_1^* \,]$.

$\alpha_2 = [\, 1/T_3^* - 1/T_1^*] = [\, 1/T_3 + K_e n_e - 1/T_1 + \delta_p n_3] > 0$ only at very high currents . (17).

$\alpha_3 = [\, 1/T_4 - 1/T_3^*]$.

T_2 is an effective plasma relaxation time for the neon's $^1P_1$ excited level while T_3^* is a plasma relaxation time and the D E I I interaction and is given by the term $1/T_3^* = 1/T_3 + K_e n_e$. T_4 is a diffusion dominated relaxation term.

At long times, T_1 and T_2 are the short relaxation times and Δn_1, $\Delta n_2 \rightarrow 0$. The most significant contribution to the OGS comes from the terms Δn_3 and Δn_4 at longer times. From equation (5) we get that the OGS is given by:

$$\Delta V = -\beta \{ a_3 \Delta n_3(t) + a_4 \Delta n_4(t) \} . \qquad (18).$$

We assume that $a_3 > a_4$ according to the fact that ionizing neutral atoms of mercury requires low energy electrons which exists in relativly high densities in comparison with the second ionization process which requires high energy electrons that exists in relativly low densities according to the electron distribution in the steady state discharge. Always $\Delta n_3(t) \geq 0$ and contributes the negative part of the OGS while $T_4 > T_3^*, T_2, T_1^*$. The term $\Delta n_4(t)$ can be written as:

$$\Delta n_4(t) = \{\delta_p n_3 \Delta n_0/\alpha_1\}\{[(K_e n_e)/(K_e n_e + 1/T_3 - 1/T_4)] - 1\} * [e^{-t/T_4}] \qquad (19).$$

We see that $\Delta n_4(t) \leq 0$ as $1/T_3 > 1/T_4$ and contributes the positive part of the OGS. Both equations (15) and (16) contain the same multiplication term $\delta_p n_3 \Delta n_0$ and simplificationis introduced by taking the reduced vertions of (15) and (16).

$$\Delta n_3^*(t) = \Delta n_3(t)/\delta_p n_3 \Delta n_0 \qquad (20).$$

$$\Delta n_4^*(t) = \Delta n_4(t)/\delta_p n_3 \Delta n_0 \qquad (21).$$

As $T_4 > T_3 >> T_1$ therefore $1/T_1 >> 1/T_3 > 1/T_4$ and we can drop the term $(-1/T_4)$ from the dominator of (19). Hence we get:

$$\Delta n_3^*(t) \cong [e^{-t/T_1^*} - e^{-t/T_3^*}] / [(1/T_3 + K_e n_e) - (1/T_1 + \delta_p n_3)] \quad (22).$$

$$\Delta n_4^*(t) \cong \{1/(1/T_1 + \delta_p n_3)\} \{[(K_e n_e) / (K_e n_e - 1/T_4 + 1/T_3)] - 1\} * e^{-t/T_4} \quad (23).$$

At high cathode temperature n_3 increases exponentially and as

$\delta_p n_3 > K_e n_e$, Eq (20) can be reduced to :

$$\Delta n_3^*(t) \cong [e^{-t/T_3^*}] / (1/T_1^*) > 0 \quad (24).$$

Now we can compare the contributions of $\Delta n_3^*(t)$ and $\Delta n_4^*(t)$ that can dictate the shape and the value of the OGS under the condition.

$a_3 > a_4$ as discussed earlier.

EXPERIMENTAL RESULTS AND DISCUSSION

The detected optogalvanic signal at current reached 1.3mA (Fig(4a)) shows that there exists a region where the voltage across the discharge tube drops at time longer than 150 µS after the laser pulse ended and reaches its lowest value 20µS later. This indicates that the discharge current density increased although we have decreased the Penning ionization rate through laser illumination at 588.2 nm which depleted the metastable level. We suggest that the total ionization enhancement is created by a temporal increase of the direct electron impact ionization rate due to the additional atomic vapor of mercury that would have otherwise participated in the Penning ionization process. The major reasons that support our assumption that this domination occurs are :

a) The high vapor pressure of mercury dictates a lower electron temperature "distribution" when the mercury's vapor density is higher

than that of neon . This occurs when.the cathode temperature is about 450 K ° (Fig(5)) .

b). The multi-step excitation cascade of mercury through direct electron impact ionization process starts at excitation energy electrons of 4.68 ev in comparison with the neon excitation energy of 16.67ev required for the first excited state . The density of such energetic electrons is very low according to (4) .

c). The first excited multiplate of mercury contains two semi-metastable states ($^3P_2$ and $^3P_0$) with a long life time that supports the multi-step ionization process.

We modify the four states theory in order to take into account the the increasing role of the mercury vapor atoms in dominating the discharge

A). At currents(2>i>1.2)mA (high cathode temperature) a high density of evaporated mercury exsists. Therefore the direct electron impact ionization process is the superior ionization process in the discharge tube as $K_e n_e >> 1/T_3$. The term $\{ [(K_e n_e) / (K_e n_e - 1/T_4 + 1/T_3)] - 1\}$ in (23) is almost zero as $K_e n_e > 1/T_3 > 1/T_4$. We obtain that $\Delta n_4(t) \rightarrow 0$ and $\{ a_4 \Delta n_4(t) \} \cong 0$. The remaining term is $\{a_3 \Delta n_3(t)\}$, thus, the OGS shows a negative voltage signal;

$$\Delta V = -\beta \{ a_3 \Delta n_3(t)\} < 0.$$

This behavior was detected experimentally Fig (4A). The measured values of T_i are: T_4**=500µs**,T_3=330µs, T_3^***=111µs** , T_1**=10µs** T_1^* **= 0.34µs** and T_2**=7.2µs**. The value of T_1 is taken from [4] (this relaxation term is evaluated from OGS in Na/Ne at i=2mA, where Penning ionization process has not been observed there), andT_3 is calculated by substituting the estimated value of $K_e n_e \cong 6*10^3 s^{-1}$ in the relation $1/T_3^* = 1/T_3 + K_e n_e$

We have tried to test our model against the calcium data although this data has been taken at different current. For the calcium case the relaxation times [3] are: $1/T_1* = 0.15\mu s^{-1}$, $1/T_3* = 0.019\mu s^{-1}$, $1/T_4 = 0.15\mu s^{-1}$, $\gamma_p n_3 = 10^5\ s^{-1}$ and $K_e n_e = 5*10^3\ s^{-1}$.

Putting these values in equations (15) and (16) and dividing the obtained result of Δn_3 and Δn_4 with those of the mercury we obtain $\Delta n_3(Ca)/\Delta n_3(Hg)=0.26$ while $\Delta n_4(Ca)\neq 0$ .This indicates that the calcium contribution to the negative OGS is small compared to that of mercury but it has a positive contribution to the OGS. The recorded Ca's optogalvanic signal [3] at 8 mA mainly approved our assumptions that the Ca density ($\sim 10^{14}\ cm^{-3}$) is too small compared with mercury ,thus the D E I I rate is low .

B). At currents above 2mA the cathode is very hot , n_3 is high (Fig 5)). The term $\Delta n_3^*(t) = \Delta n_3(t)/ \gamma_p n_3 \Delta n_0$ is very small $1/T_3 > 1/T_4$ and $K_e n_e > 1/T_3$, and the term $\Delta n_4^*(t) \to 0$. The only considerible contribution to the OGS comes from $\Delta n_3(t)$.

$$\Delta n_3(t) = -\{\gamma_p n_3 \Delta n_0 / \alpha_2\} [e^{-t/T_3*} - e^{-t/T_1*}] \geq 0. \qquad (25).$$

$$\alpha_2 = [1/T_3 + K_e n_e] - [1/T_1 + \gamma_p n_3] \cong -[\gamma_p n_3]$$

Thus the term $\Delta n_3(t)$ is small as both the currents and the time relaxation terms are increased. Therefore The OGS at $t > 50\mu s$ is essentially negative and small.

At low currents ($i < 1.2mA$) the cathode temperature is low. Accordingly the evaporation rate of mercury is low ($n_3 \cong 2*10^{14} cm^{-3}$). At this stage the sputtered density of mercury ($10^{14} cm^{-3}$) is non negligible. Here we assume that Penning ionization process dominates the total discharge

ionization process. The major cotribution to the OGS comes from:

$$\Delta n_3^*(t) \cong [e^{-t/T_3^*}] / [(\delta_p n_3 - K_e n_e) + (1/T_1 - 1/T_3)] \qquad (26).$$

$$\Delta n_4^*(t) \cong -1/T_1^* \{1 - K_e n_e / (K_e n_e + 1/T_3)\} [e^{-t/T_4}]$$

$$- [K_e n_e e^{-t/T_3^*}] / \{(1/T_3^* - 1/T_1^*)(1/T_4 - 1/T_3^*)\} \qquad (27).$$

Equation (26) describes a negative behavior of the OGS at $(t<T_4)$. This negative contribution from $\Delta n_3^*(t)$ is partially diminished by the last term in (27). Experimentally, the detected OGS At $t<100\mu s$ exhibit a moderate negative voltage signal as is shown in Fig(4b).

At $t>t_4$, the most significant contribution to the OGS comes from $\Delta n_4^*(t)$ and it is a positive one. This contribution comes from the first term in (27). We can obtain an additional positive contribution to the OGS by adding the sputtering rate term $I \delta_s \Delta n_4(t)$[3] which we have neglected earlier to the rate equations. (Here, I is the discharge current and δ_s is the Penning and the self-sputtering coefficient). Thus at low currents the OGS mainly exhibits a positive voltage signal that decays slowly as seen in Fig(3b), and it is quite similar to the detected OGS in Ca/Ne tube at 6.4 mA [3].

SUMMARY

The experimental OGS exhibits two different states which are related directly with the current. At currents below 1.2mA the OGS shows a Penning ionization signiture which is simmilar to the Penning ionization of Ca discussed in Ref (4), while at currents above 1.2mA the detected OGS exhibits a current density enhancement due to a highly thermal evaporated rate of mercury from the cathode that helps the D E I I process to controll the discharge.

We have expanded the resonant optogalvanic theory (3-5) to deal with a case where the sputtering process has lost it's major monopolized role of supplying the metal atomic vapor to the ionization processes to maintain the discharge in the steady state. This is the state where the direct electron impact ionization process increases the current density and controlls the discharge.

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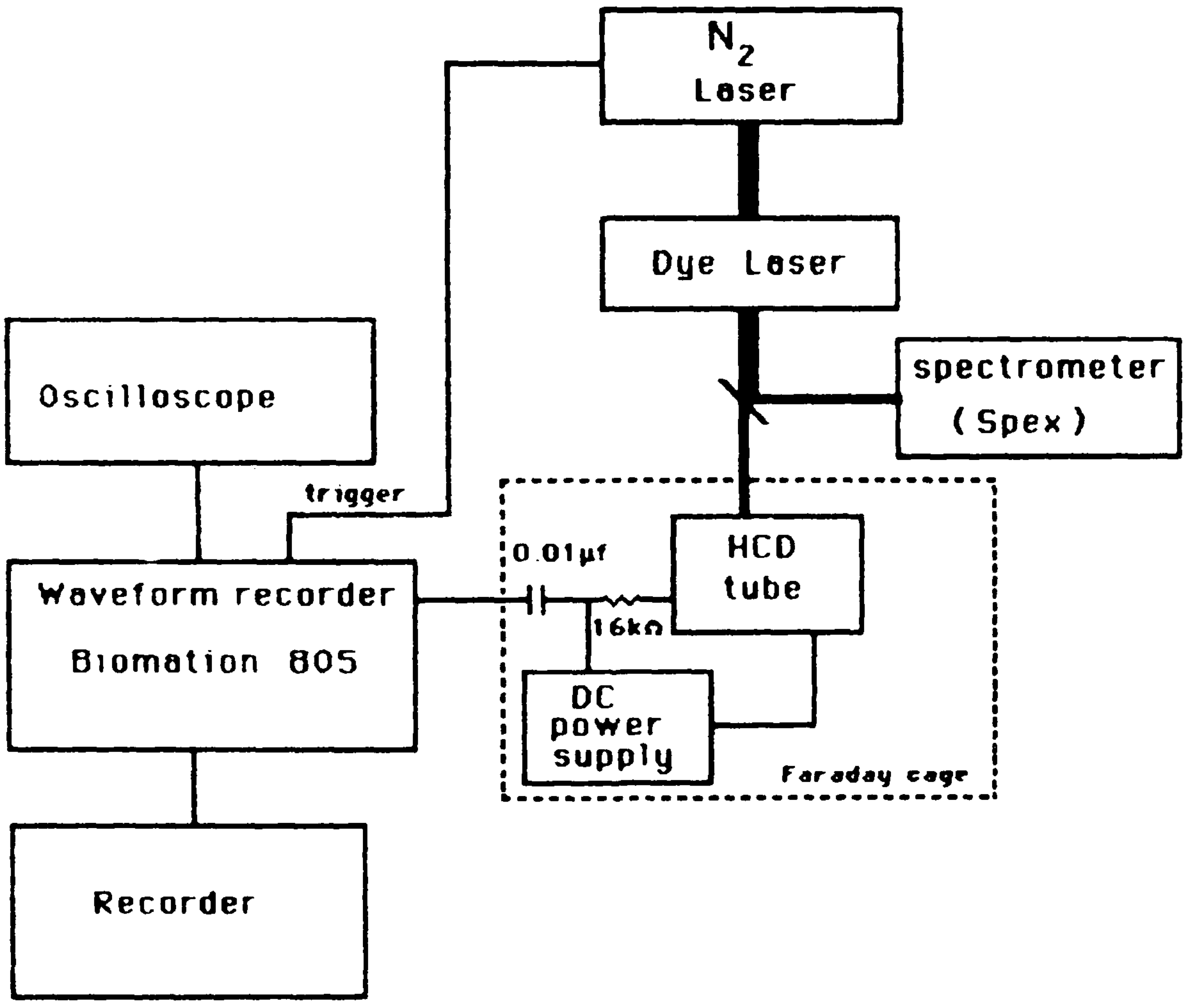

Fig (1) The experimental detection setup of the pulsed optogalvanic signals

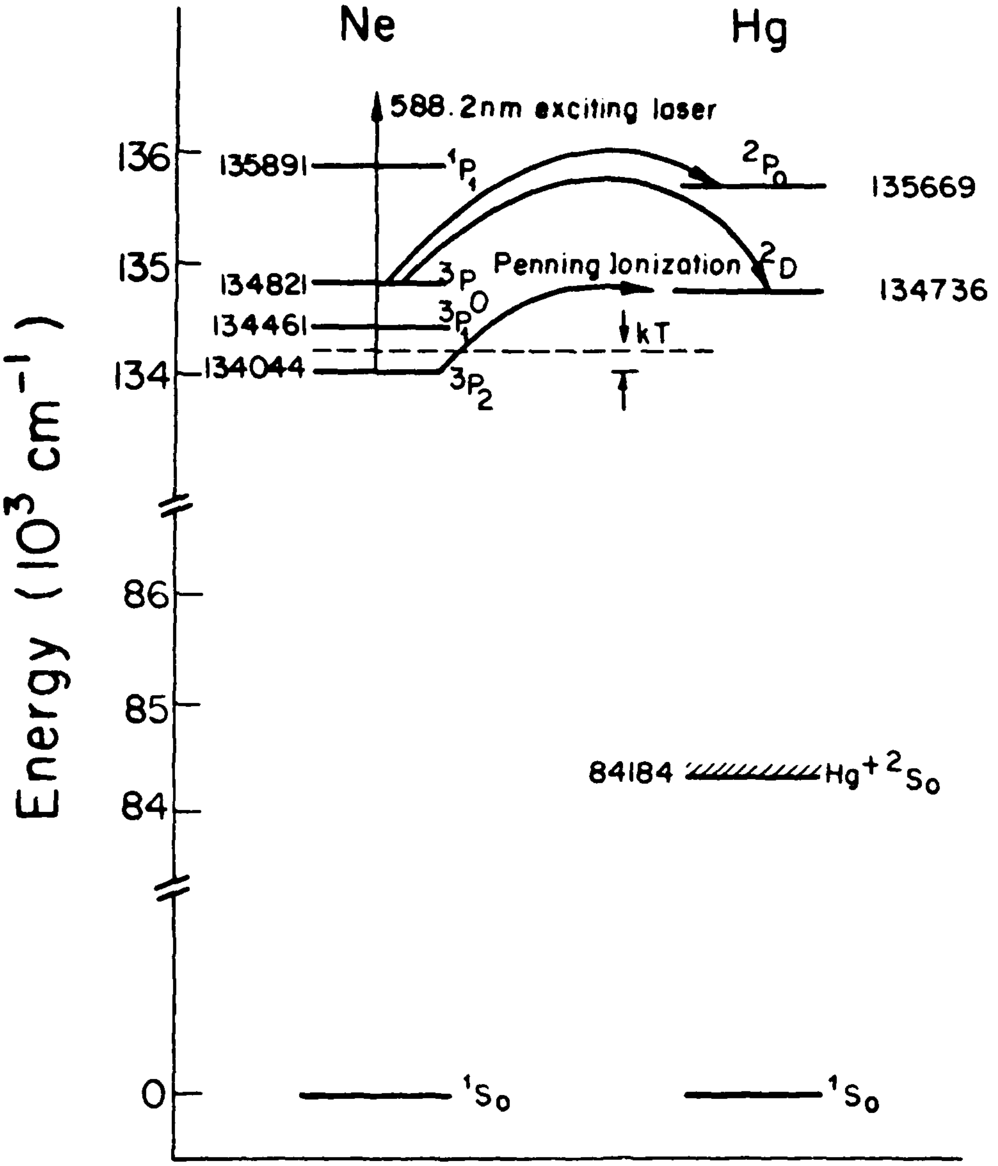

Fig (2) Energy level diagram of Hg/Ne system pertaining to the Penning ionization process.

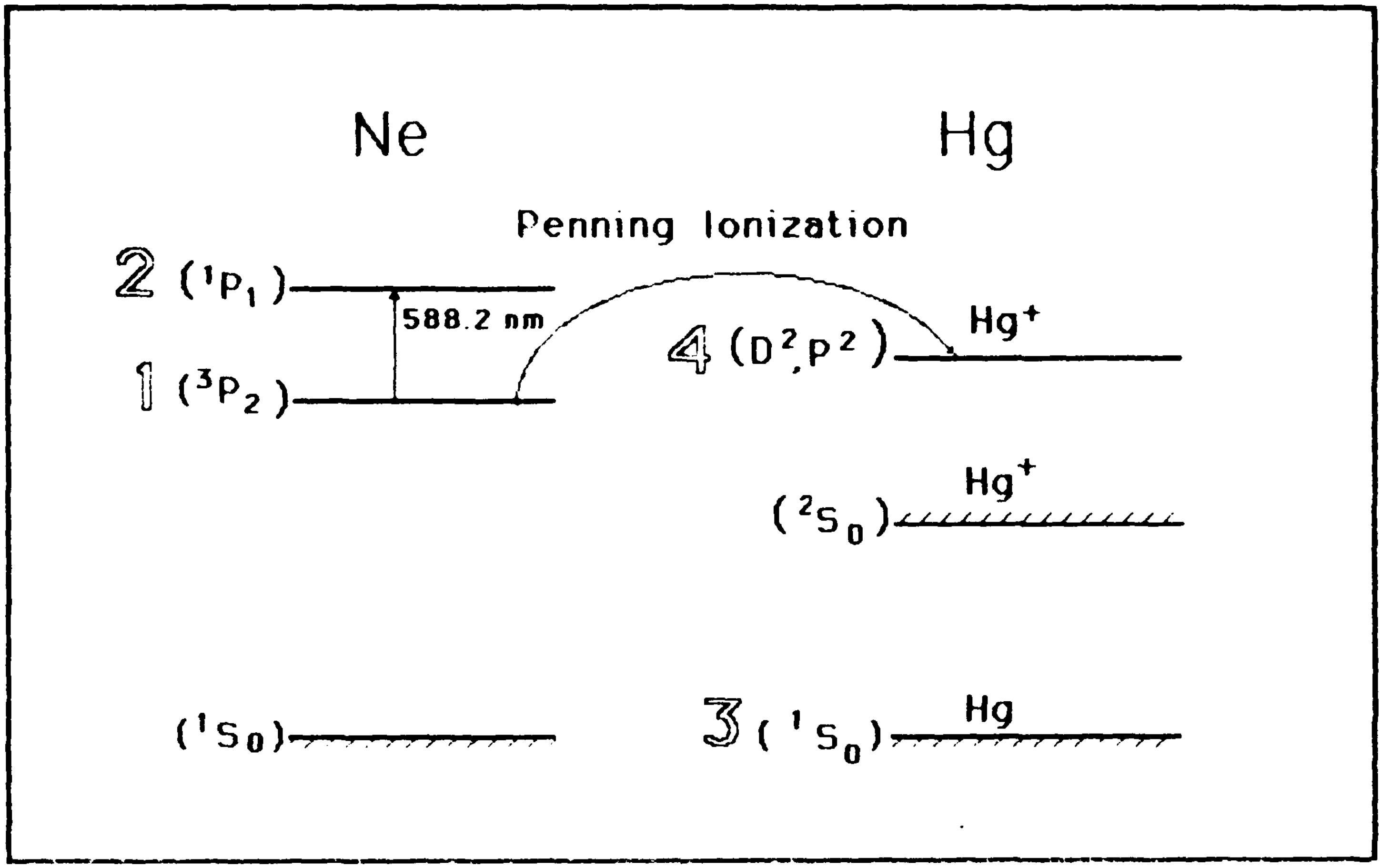

Fig (3) The four energy levels of thr system Hg-Ne that has the major contribution to the optogalvanic effct in presence of Penning ionization of Hg by excited metastable Neon levels .

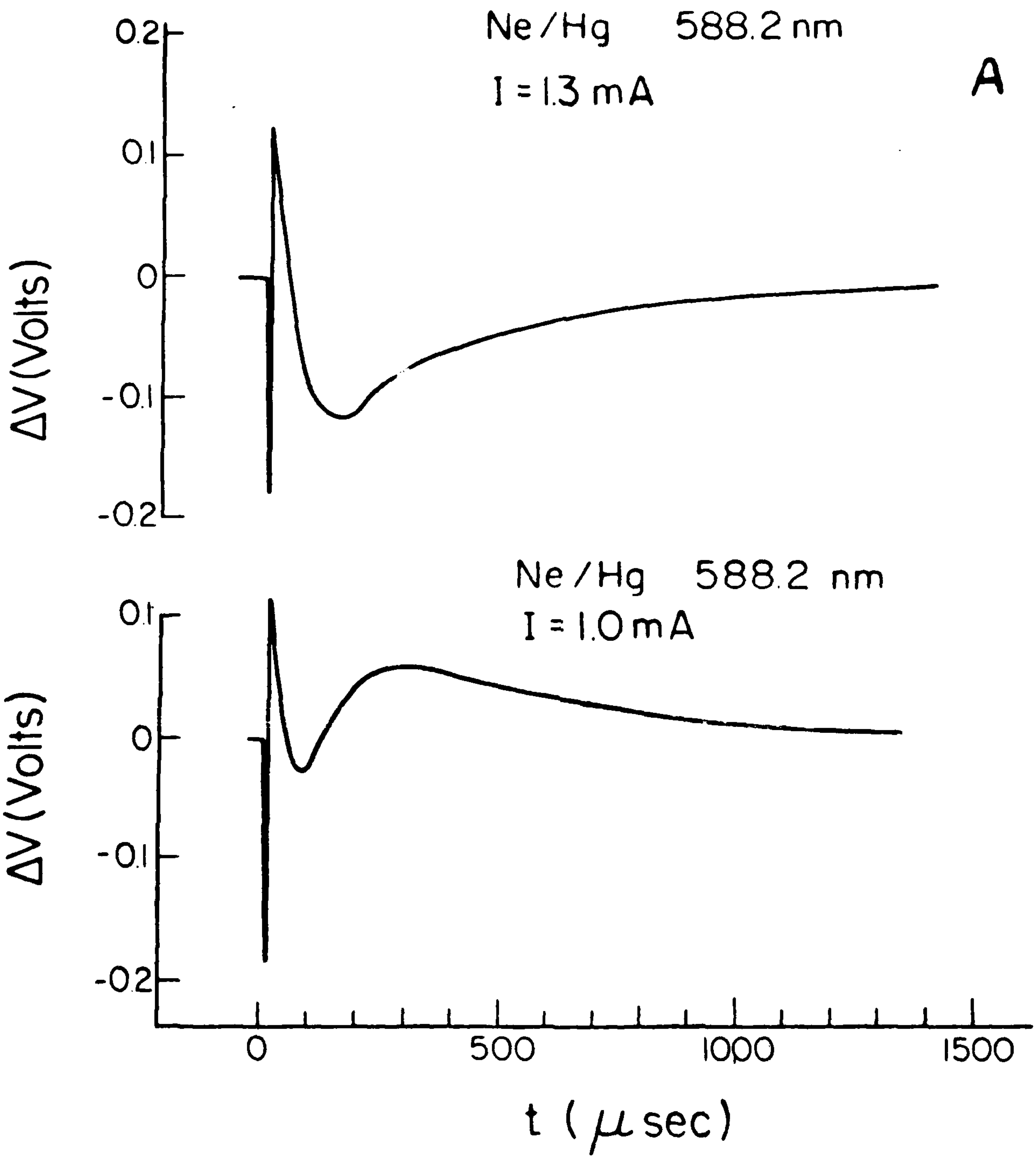

Fig (4) OGS of the $1s_5$--$2p_2$ transition at 588.2nm for two currents. Part a is taken at 1.3mA, and exhibits the ionization enhancement when D E I I process dominates the discharge, part b was taken at 1mA and exhibits the usual Penning contribution.

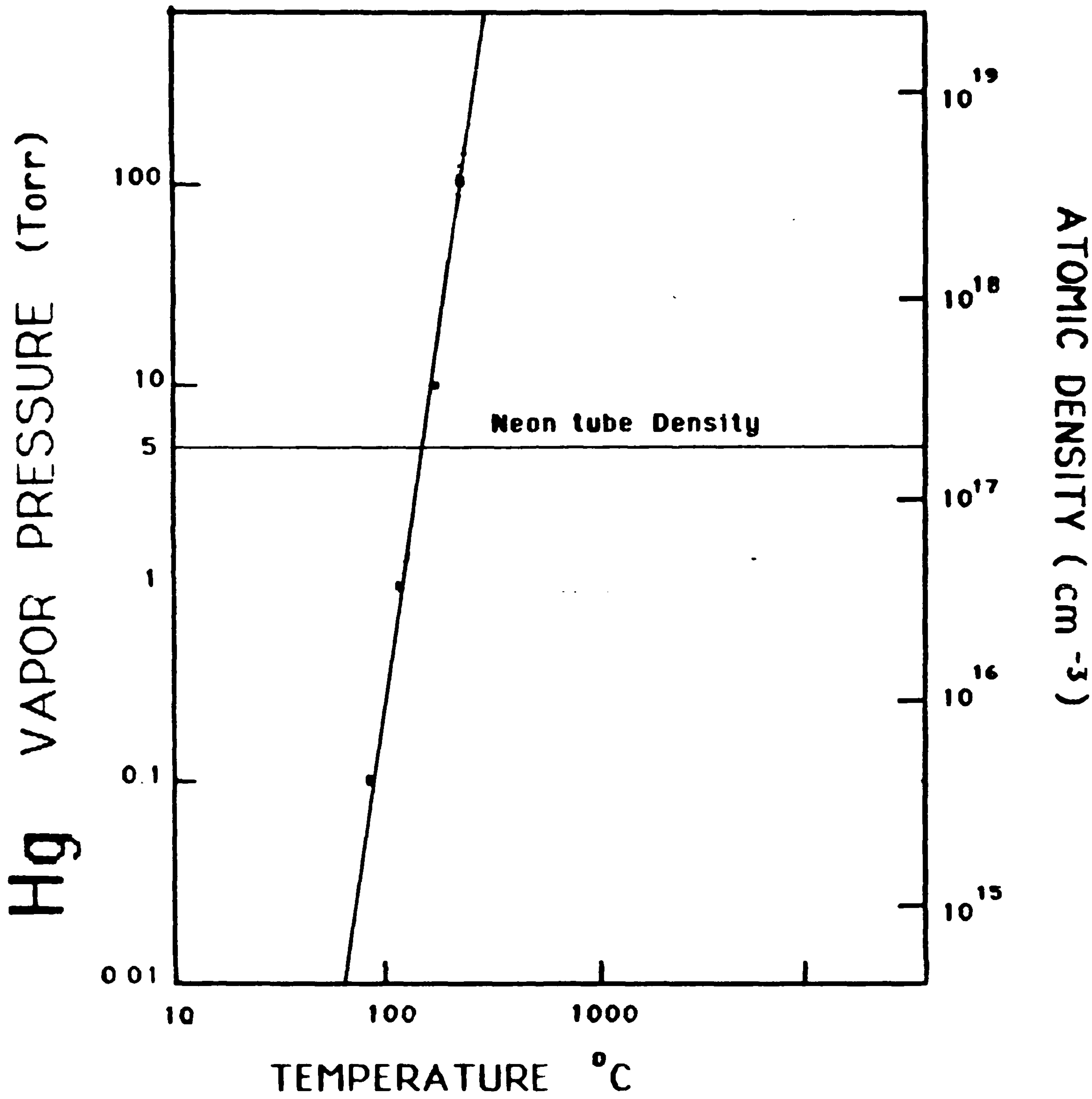

Fig (5) The density and the vapor pressure of mercury as a function of the temperature, (Ref 6).

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